Amendments to the Specification

Please replace the indicated paragraphs of the specification with the amendment paragraphs below.

[0024] As noted previously, airflow can be expressed as either the mass or volume of gas per time. It is common within the industry to express airflow as "standardized volumetric airflow in SLPM (standard liters per minute) or SCFM (standard cubic feet per minute). These are volumetric values "standardized" to specific air temperature and barometric pressure and are useful because they reflect the heat carrying capacity of the air. Regardless of how airflow is expressed, it must first be measured and there are several ways of measuring airflow. Some methods measure the velocity or deflection of an impeller, pith-ball, or other mechanical indicator and then readings must be arithmetically compensated temperature, barometric pressure and humidity to determine standard airflow in units, such as SCFM or SLPM. Some methods measure "mass airflow" and measurements do not need to be compensated. A sensor that uses the latter measurement method can be referred to as a mass airflow sensor. Sensors that measure using either technique are acceptable for implementing embodiments of the present invention.

[0029] FIG. 1 is a block diagram of an embodiment of an air sampler that works on the principles just described. Air sampler 100 includes air moving arrangement 102, which can be a fan, pump, or other device. Air moving arrangement 102 is disposed to draw air through the system, following the path of the arrows. Air to be sampled enters at 104 and exhausts at 106. Air to be sampled enters the sampler's air inlet[[,]] 108, which for illustrative purposes can be assumed in this example to include any pickup hoses or passages. Air then enters the sampling media assembly[[,]] 110, which includes any slide or similar conveyance containing the media that is to capture the contaminants. Airflow sensor 112, which in this example works as described above, is disposed to be in fluid communication with, and in the path of the airflow between, sampling media assembly 110 and air moving arrangement 102. A filter[[,]] 114, may optionally be included to protect airflow sensor 112, air moving arrangement 102, and other downstream components from larger contaminants and particulates. Air exits air exhaust assembly 115, which may include additional muffling to quiet the unit or filtering to protect the

environment from small amounts of lubrication or dirt that may be added to the post-sampled air stream by the sampler. Any filtering lessens the likelihood that the sampler will inadvertently contaminate a previously uncontaminated environment. Control system 116 provides air mover control and can also provide airflow feedback as described above and will be discussed in greater detail below.

[0030] As previously discussed, the principles of the invention can be applied to a variety of types and configurations of air samplers. Thus, a sampling media assembly and sampler air inlet and/or pickup may be included in a self-contained unit. U.S. Patent Number 5,201,231 describes such an air sampler, although without any airflow feedback, and is incorporated herein by reference. Air samplers in which the air mover is a pump typically do not, although may, have an integrated sampling media assembly. A separate sampling media assembly that can be used with such an air sampler and its use are <u>both</u> described in U.S. Patent 6,692,553, which is incorporated herein by reference.

[0031] Returning to FIG. 1, control system 116 in this example includes controller 118. Controller 118 has built-in multi-channel A/D converter functionality, represented by A/D conversion blocks 120, 122, and 124. Controller 118 also has built-in memory, 126. An example of but one of many suitable controllers for implementing a feedback control system according to this example embodiment is the Microchip™ PIC18F452 microcontroller available from Microchip Technology, Inc. of Chandler, AZ, USA. Signaling received from the airflow sensor by the microcontroller in this example includes signal voltage 128 representing the heated airflow sensor outlet temperature, which is fed to A/D conversion block 124, and signal voltage 130 representing the airflow sensor inlet air temperature, which is fed to A/D conversion block 122. This particular example embodiment includes an external temperature sensor[[,]] 132, which feeds a voltage representing ambient temperature to A/D conversion block 120. In many cases, with the two temperature signals coming from the airflow sensor, such an external temperature sensor is not needed since the temperature sensed would be the same as the unheated temperature from the airflow sensor. It can optionally be included however, either for verification of the operation of the airflow sensor, or to provide a local temperature reading in

cases where the sampled air is being drawn from a location remote or separate from the air mover, such as from inside a wall with a wall probe. In the embodiment of FIG. 1, controller 118 outputs a binary number to adjust the operating speed of air moving arrangement 102. This number is converted to an analog voltage by a separate digital-to-analog (D/A) converter[[,]] 134.

[0032] FIG. 2 illustrates another embodiment of an air sampler according to the present invention. In FIG. 2, many components in the system are identical to those shown in FIG. 1 as evidenced by like reference numbers. However, airflow sensor 212 in this case is a self-contained unit that outputs a voltage signal[[,]] 230, that is indicative of airflow. Such sensors may be purchased off-the-shelf, and may or may not include integrated inlet and outlet temperature sensors, heaters, and other components necessary to derive an airflow signal. One example of an off-the-shelf airflow sensor that can be used to implement an air sampling system according to an embodiment of the invention is the Honeywell™ AWM720P1 Airflow Sensor, Available from Honeywell, Inc. of Freeport, Illinois, USA. Details of how to program the Microchip microcontroller for use with this Honeywell airflow sensor according to an example embodiment of the invention will be discussed later with respect to the flowcharts and lookup table included in the Figures.

[0033] Control system 216 of FIG. 2 includes controller 118 as before, but only a single A/D converter block or channel[[,]] 224, is used to receive the airflow voltage signal that constitutes the signaling from the airflow sensor in this example embodiment. The speed control and external temperature portions of the air sampler of FIG. 2 are identical to the example of FIG. 1, as indicated by the like reference numbers. Note that a sampler like that shown in Figures 1 and 2 can be constructed with any of various types of airflow sensors, either self-contained, or constructed from multiple components that work together to measure airflow.

[0035] FIG. 3 is a conceptual block diagram of another embodiment of an air sampler. FIG. 3 illustrates at least a portion[[,]] 300, of an air sampler. This particular example illustrates a mechanical feedback control mechanism. Again, in FIG. 3, the arrows indicate the stream. Air

moving arrangement 302 can be a fan, pump, or other device as before, including an air moving arrangement that consists of a fan or pump and a valve that ~~adjust~~ adjusts the effective, operating speed or airflow of the air moving arrangement. Airflow sensor 312 in this example uses a mechanical fin[[,]] 319, the degree of deflection of which indicates airflow. Spring 321 and rod 329, are connected to fin 319 just above pivot point 345. Thus, in this example, a mechanical linkage provides the "signaling" corresponding to airflow. Adjustment device 325 alters the effective speed of air mover 302. Adjustment device 325 can be, for example, a valve control. User input device 335 in this example is a mechanical slider that allows spring 321 to be anchored at any of various physical positions[[,]] 339 to allow increase or decrease in airflow by indirectly moving adjustment device 325 as indicated in the drawing legends.

[0036] FIG. 4 provides a detailed block diagram showing the construction of a controller board[[,]] 400, based on the previously mentioned Microchip microcontroller. Because of the number of components shown in this illustration of an example controller board, the diagram is split into two parts, labeled FIG. 4A and FIG. 4B. Such a controller board can be used in the implementation of a control system according to example embodiments of the invention. Note that in this example, the control system implements both an airflow feedback mechanism, and user adjustable airflow, however, an embodiment of the invention might make use of integrated airflow sensing or measurement to implement only one of these features or other features. For convenience, connections to some components that are located within an air sampler according to an example embodiment of the invention, but which are not on the controller board are also shown, along with the components or component groups themselves. Note also that in this example embodiment, a daughter-board[[,]] 402, is also shown that contains a display. Also note that the terms "controller" and "microcontroller" may be used interchangeably herein.

[0037] FIG. 4 includes microcontroller 404 as previously discussed. The microcontroller can be designed to operate anytime it is connected to a battery or other power supply. It can also be programmed to change to a power conserving "sleep" mode when user activity ceases and there are no samples currently running. Once in the sleep mode the microcontroller in this embodiment only wakes up at periodic intervals as necessary to maintain its internal, real-time

clock/calendar and check for sample time "wake alarms"; thereafter it immediately goes back to sleep if none are detected. In example embodiments, the microcontroller wakes up and stays [[away]] awake whenever it senses that a user button has been pressed, or when it determines it is time to take a user programmed, timer activated sample. During this "wake up" event, the user display is switched on and all of the sensors are powered. The microcontroller can be programmed to go back to sleep some preset period of time after the last user button is pressed if no sample is being taken at the time.

[0038] The microcontroller used in this example embodiment has an internal, 8 channel, 10 bit A/D converter, which functions the same as [[8]] eight separate voltmeters, each of which is capable of reading up to 1024 unique voltage values ranging from 0 to 5.0 VDC. Example embodiments of the invention are implemented by using fractional multipliers with a denominator of 256, since dividing by 256 in binary is analogous to dividing by [[10]] ten in decimal.

[0039] Returning to FIG. 4, a reset circuit[[,]] 406, is provided for microcontroller 404. In addition, the microcontroller includes its own reset circuit, and a so-called "watchdog" timer to reset the microcontroller should it ever become "lost" in its program execution, so that an external reset circuit may not be needed depending on whether there is a desire to provide features, such as low voltage detection (or "brownout detection"), with less power consumption. A four line, liquid crystal display (LCD) user screen 408 is provided in this example. A display device is used in this embodiment that does not provide for direct user adjustability of the contrast or backlight. Microcontroller 404 indirectly adjusts the contrast of the LCD display by controlling the DC voltage to a contrast adjust pin using D/A converter 410. The backlight for the display is controlled by modulating voltage to the display's backlight circuitry using one of the microcontroller's pulse width modulation (PWM) outputs in conjunction with a buffer transistor[[,]] 412. Of course, normal user signaling for the displayed characters is provided by signal path 414 as is known in the art.

[0040] In this example embodiment, three user push button switches[[,]] 416, are included. These switches are referred to as "soft" switches since their function is dependent upon the user screen displayed at the time pressed. The bottom line of the user screen can be made to label the function of each of the three switches, which are located immediately below the screen. If the display is not active when a switch is pressed, the controller "wakes up" and displays either a main screen or another screen as appropriate.

[0041] Microcontroller 404 is connected to low frequency crystal 418 and high frequency resonator 420 to provide appropriate clocking. The controller in this example design has two separate oscillators. An 8 MHz oscillator that is resonator based and another 32.768 kHz that is crystal based. Both oscillators are internal to the microcontroller and have different functions. The 32.768 kHz crystal based oscillator drives a timer/counter internal to the microcontroller and is responsible for generating interrupts to the microcontroller at exactly one-second intervals. This low frequency, low power, oscillator runs anytime the microcontroller is powered; including during "sleep" mode. The 8 MHz resonator based oscillator which consumes more power is only operated when the controller is awake. The use of this 8 MHz frequency gives the processor an instruction cycle time of 8/4 = 2 MHz. Most, but not all, of the microcontroller's instructions execute in [[1]] <u>one</u> instruction cycle, so overall performance in this example embodiment is a little less that 2 MIPS.

[0043] As previously mentioned, the invention can find use in a variety of types and styles of air samplers and air sampling systems. In the example embodiment shown in FIG. 4, provisions are made for use in a sampler with a self-contained media assembly of the type where a microscope slide is incrementally moved to collect samples at regular intervals. This is the type of sampler described in U.S. Patent 5,201,231, which was previously discussed. In this case, [[a]] stepper motor driver components[[,]] 428 are provided to control a linear actuator stepper motor[[,]] 430, which is used to move the slide from one sample position to another. Similarly, for use in such a sampler, position sense switch 432 is provided to sense the starting position of the slide. With these connections to microcontroller 404, the rotation step angle and number of

stepper motor rotations can be precisely controlled by microcontroller 404 so movement of the slide is inherently precise.

[0044] D/A converter 434 in the example of FIG. 4 feeds voltage controlled voltage regulator 436 to provide operating speed control to the air sampler's blower or pump 438. Depending on the type and design of the air mover used, the control voltage can actually be the supply voltage for the air mover, or a separate control signal. Other example embodiments for operating speed control include modulating a voltage to vary [[it's]] its duty cycle, and running the fan, pump, or similar device at a constant real operating speed but varying the effective operating speed or airflow of the air moving arrangement by using a voltage to adjust a cutoff or bypass valve to vary the amount of air being moved. For purposes of this disclosure, any discussion of adjusting or changing the "speed" or the "operating speed" includes all of these alternatives.

[0046] Temperature sensor 440 is connected to controller 404 through an operational amplifier-based amplification and offset circuit, 441. In some example embodiments, the temperature sensor can be a National Semiconductor™ LM62 temperature sensor available from National Semiconductor Corporation of Santa Clara, California, USA. This circuit board mounted sensor outputs a voltage proportional to Centigrade temperature; more specifically, at 0° C the sensor outputs 480 millivolts and the output increases by 15.6 millivolts for each Centigrade degree. Each A/D converter in controller 404 has up to [[10]] ten bits of resolution which results in 4.88 millivolts / bit sensitivity with a 5.0 VDC power bus. The amplification and offset circuit[[,]] 441, is applied to achieve a resolution of 0.1° C for each A/D converter bit. In this example embodiment, a user calibration routine is provided to ensure accuracy of the measured, external temperature within a window of a few tenths of a degree.

[0047] This example embodiment includes a humidity sensor[[,]] 442, connected to one of the A/D channels of the controller. One example of a humidity sensor that can be used is the Honeywell™ HIH-3610 humidity sensor. With such a sensor, a humidity dependent voltage output ranging from 0.8 to 3.9 VDC is produced. This humidity sensitive voltage level output is affected by changes in temperature and if use is made of such a humidity sensor, the software for

the controller should be written to compensate the displayed humidity value using measured air temperature from the external temperature sensor to ensure optimal accuracy. Alternatively, temperature compensation could be provided in hardware.

[0048] In the example of FIG. 4, barometric pressure sensor 444 is connected to one of the A/D inputs of microcontroller 404 via amplification and offset circuit 446. One example sensor that can be used to provide barometric pressure indication is the Motorola™ MPXA6115 barometric pressure sensor, available from Motorola, Inc, of Schaumburg, Illinois, USA. In one embodiment, in order to provide barometric pressure measurement at altitudes ranging from approximately sea level (29.92" Hg) to 10,000 ft (20.57" Hg) while allowing +/- 1.00" Hg for weather, the controller should display a total range of pressure from 29.92 – 20.57 + 2.00 = 11.35 with 0.01" Hg resolution. The resulting 1135 count from the Motorola sensor exceeds the 1024 count resolution of the microcontroller's 10 bit A/D converter. In order to match the output voltage of the barometric pressure sensor to the 0.01" Hg resolution of the A/D converter, amplifier and offset circuit 446 should have a gain of 3.1414. Allowances must also be made for the minimum pressure offset of the sensor, which is specified to vary up 0.133 VDC. The 3.1414 gain multiplied by the 0.417 VDC offset and divided by 4.8828 millivolts per bit results in need for another [[85]] <u>eighty-five</u> bits on top of the 1135. Since only 1024 bits of resolution are available with a 10 bit A/D converter, a user can only read barometric pressure within a +/- 5.00" Hg (+/- 500 A/D counts) window both above and below the last user set barometric pressure. Whenever the user sets the barometric pressure, microcontroller 404 iteratively adjusts this offset voltage to barometric pressure sensor amplifier and offset circuit 446 so that the resulting output is approximately half of the available measuring range. Barometric pressure display should then be capable of measuring approximately 5.00" Hg pressure change both above and below the user's last barometric pressure setting.

[0049] In the particular example embodiment corresponding to FIG. 4, the air sampler is provided with a self-contained, off-the-shelf integrated airflow sensor[[,]] 448. In one example, the airflow sensor used is the previously mentioned Honeywell AWM720P1 Airflow Sensor. Amplification and offset circuitry 450 interfaces the airflow sensor to controller 404. Circuitry

450 also includes filtering to remove air mover impulses that can be introduced into the airflow sensor output, in particular, when a pump is used. Further detail of implementing an example embodiment of an air mover according to the invention using this sensor is discussed in relation to the flowcharts which illustrate the operation of an example air sampler, and in relation to FIG. 9.

[0050] Controller board 400 contains additional components and connections which relate to powering the various components, although the power supply connections for the controller and related circuits are as is known in the art and are not shown for clarity. Connections are provided for a power supply adapter[[,]] 452, for optional AC power and battery charging, and for a battery[[,]] 454. A voltage controlled power supply and battery charger[[,]] 456, is provided to charge the battery and power the air mover via voltage regulator 436. <u>D/A converter 457 is connected between microcontroller 404 and voltage controlled power supply and battery charger 456.</u> A 5.0 VDC supply voltage is also provided by voltage regulator 458. A switched 5.0 VDC voltage is provided by switch 460. The switched supply voltage can be used to supply power to components, such as sensors, that can be switched off in order to allow controller 404 and its installed firmware or microcode to better manage the power consumption of the air sampler. Additional features and components can be provided for power and battery management as is known in the art. These might include, among other items, charge status indicator lamps or LED's, a battery disconnect relay, and battery voltage sensing and adjustment circuitry.

[0062] FIG. 6 is a flowchart style diagram illustrating an airflow feedback process[[,]] 600, according to example embodiments of the invention. In typical use, an air sampler runs for a plurality of "sample periods" to collect samples to be analyzed. The flowchart of FIG. 6 illustrates the process of providing airflow feedback for a single sample period. The process can repeat for each sampling period. The sample starts at block 602. When a sample is started, the air moving arrangement begins running either at the calibration speed stored in non-volatile memory at the time of calibration, or an operating speed saved in memory at the end of the previous sample. The former can be used in the case of the first sample after setup. For the remainder of the samples, either value can be used. This choice can be implemented as a user

setting via a menu, or the choice can be permanently programmed into the air sampler. In either case, the stored setting is retrieved from memory at block 604. The objective is to start the air moving arrangement running at a speed close to what it will be when operating in feedback. At blocks 606, 608, and 610, null offset information can be updated to account for changes in environmental readings, such as temperature, during the off period between samples, or during any time that has elapsed since calibration if this is the first sample. These steps can be performed in essentially the same way as they were during calibration. The air moving arrangement starts at block 612.

[0066] FIG. 7 breaks out in further detail, an example sub-process, 700, of the feedback process itself. The actual, temperature compensated, current airflow is being calculated based on sensor voltage at block 702. Measured airflow is then compared with target airflow at block 704. If measured airflow is substantially equal to target airflow at block 704, no air mover speed adjustment is made and there is a waiting period of 0.8 seconds imposed at block 708 before calculating and comparing airflow again. If instead the airflow has drifted from the target airflow, then the air moving arrangement speed count is either incremented or decremented by [[1]] <u>one</u> (1 of 256) as needed at block 710, and a determination is made at block 712 as to whether the airflow is within 0.3 LPM of the target. If yes, the 0.8 second wait at block 708 is imposed before calculating and comparing again. If instead the difference between measured airflow and target airflow is more than 0.3 LPM, then a determination is made at block 714 as to whether the measured airflow is within 0.8 LPM of the target. If so, a waiting period of only 0.4 seconds is imposed at block 716 before calculating and comparing again. If not, that is, if the measured airflow is more than 0.8 LPM away from the stored, target airflow, a waiting period of only 0.2 seconds is imposed at block 718, and then the airflow is calculated and compared again at block 702.

[0069] A process[[,]] 800, of a user changing the stored, target value for desired airflow on an air sampler using a menu-driven user interface with soft keys is illustrated in the flowchart of FIG. 8. In practice, this process could be executed concurrently with, or as part of, the process of FIG. 6. The process begins at block 801. At block 802, a check is made as to whether the user

has input a target value. If so, the new target value is stored at block 805. At block 806, the air mover starts. The amplified voltage from the airflow sensor is read and the null offset is subtracted at block 807. The reading is adjusted for the span based on the output shift-with-temperature at block 808. Since the airflow is now at a different place on the airflow sensor sensitivity curve, nonlinearity compensation is added or subtracted at block 810. In example embodiments, this is done using input from a multiplier table or a calculation based on an equation as shown at block 812. Measured airflow is displayed at block 814. Normal operation ensues, in which the processes of blocks 807-814 are carried out every time the airflow is read.

[0072] Microcontrollers have somewhat limited internal hardware capability for doing arithmetic. Although software can be written to perform what is often referred to as floating point calculations; an alternative method for this example embodiment is to create a lookup table based on the polynomial equation above and have the microcontroller use this lookup table data instead of performing numeric calculations associated with the polynomial equation. An example lookup table[[,]] 900, based on the above equation is illustrated in FIG. 9.

[0074] If the airflow sensor were linear and the unit had been calibrated at 15 LPM, one would expect the net voltage output by the sensor (net = actual – null offset) at 1 LPM to be exactly 1/15 of its net voltage at 15 LPM. The Honeywell sensor used in the example embodiments described herein is non-linear and the voltage output by the sensor is actually higher than it would be if it were linear. Based on manufacturer's specification, the net voltage output by the sensor at 1 LPM is 0.093 VDC. Since the sensor outputs a net voltage of 1.313 VDC at 15 LPM, one would have expected a net voltage of 1.313 times (1/15) = 0.08753 had the sensor been linear. Since it is not linear the actual reading is 0.093 / 0.0875 = 1.062857 times the desired reading. It would be possible to correct or linearize this same data by multiplying by the actual sensor data at 1 LPM by the inverse of 1.062875 = 1/1.062875 to compensate. If one converts 1/1.062875 to a fraction having a denominator of 256, the result is (1/1.062875) times 256 = 240.86 which rounds to 241. Note that this is the number stored for 0-1 LPM value in table 900 of FIG. 9. The remaining tabular data illustrated in Table 900 FIG 9. was generated using the same technique. Sensor data was not available from Honeywell for airflow between 11 and 14

LPM, inclusive, so a plot was generated that allowed for reasonable estimation of the data values.